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Eco Global Evaluation: cross benefits of economic and ecological evaluation

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Abstract

This paper highlights the complementarities of cost and environmental evaluation in a sustainable approach. Starting with the needs and limits for whole product lifecycle evaluation, this paper begins with the modeling, data capture and performance indicator aspects. In a second step, the information issue, regarding the whole lifecycle of the product is addressed. In order to go further than the economical evaluations/assessment, the value concept (for a product or a service) is discussed. Value could combine functional requirements, cost objectives and environmental impact. Finally, knowledge issues which address the complexity of integrating multi-disciplinary expertise to the whole lifecycle of a product are discussing.

Keywords:

Costing, environmental evaluation, Value Analysis, Product Lifecycle Management, Life Cycle Analysis

1 INTRODUCTION

Sustainable concerns are increasing in the industrial sector. This paradigm has environmental, economic and social aspects (see figure 1). Most industries have turned "green" due to regulatory constraints or marketing targets. As for quality management, industries have often adopted these evolutions as non-pro-active actors. There has been a shift from ISO 9000 to ISO 14000. However, few of them have clear strategic policies linked to their priorities and on their project's return on investment potentiality. Product definitions, manufacturing possibilities, logistics strategies and end of life alternatives offer many ways to work toward sustainability.

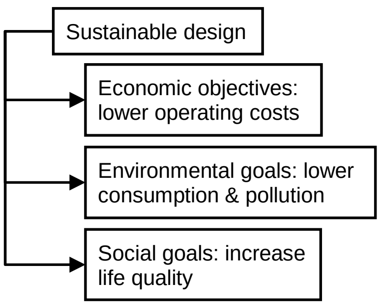

Figure 1. Sustainable design goals

The social side of the sustainable approach is hard to deal with and is out of the scope of this paper. However, this aspect should be taken into account very quickly in order to develop new services opportunities that meet consumer demand and optimize the products use ratio (real used time versus overall life time) and their environmental affect [1]. Moreover, there is a huge challenge to consider, namely consumer and engineer tutoring. People have to learn to reduce consumption and pollution in order to adapt to the world's limited natural resources. Solutions have been found in green manufacturing and green alternatives. That means products that create less pollution at all stages of the product life cycle whilst ensuring minimal consumption of non-renewable resources. In addition, consumer tutoring has to focus on the way people use the products and resources in their daily lives (like water, light, etc.).

Cost and environmentally oriented industry decisions are therefore, linked. Indeed, when engineers have to work in an environmentally-friendly way, they try to reduce the quantity of materials used and energy consumption, as a natural reflex. In this way, they do not only decrease the product's incidence on natural resources but they consequently also reduce material and energy costs in the product's cost. Section 2 of this paper will discuss the latter.

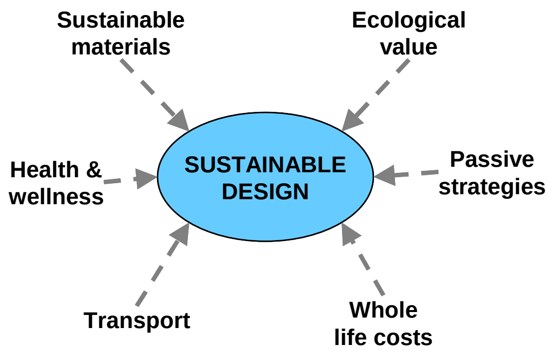

Figure 2. Sustainable design interests

In most of the cases, it is the life stage of the product that implies the most important impacts or costs. In other words, an overall cost of ownership is now the target of the designer and the marketing departments. It is the same for environmental design and the use of Life Cycle Assessment (LCA called ecobalance or cradle-to-grave analysis) [2]. As illustrated in figure 2, the whole life cycle costs are included in the sustainable design concerns and evaluations. Section 2 will discuss the needs of an integrated Product Lifecycle Management system to evaluate all the stages impacted efficiently. Products information is unclear or unknown in the early phases when decisions are made and 80% of the final costs have been determined. It is the same problem for environmental consequences.

Moreover, Product Lifecycle Management (PLM) definition requires product and processes modelling. These models provide the basis for different solutions analysis and optimization. The third section will present a value based analysis approach that enables not only cost, on one hand or environmental concerns on the other hand, to be taken into account, but also proposes a value evaluation and value definition. This section will also introduce the links between value analysis and a PLM information system for sustainable analysis.

In order to ensure reliable evaluations, the data must reflect the reality. In addition, the aggregations rules must be adapted to the product portfolio, the organization behaviour and the evaluation criteria. .In order to take advantage of previous or similar projects, it is necessary to look for the best practices for project guidelines and to locate the most important knowledge used. The last section will illustrate the use of roadmap methodologies and knowledge value evaluation to enhance and ensure the success of eco-design approaches in parallel to product costs assessment.

2 COST AND ENVIRONMENT SIMILARITY AND COMPLEMENTARITY

As for ISO 9000 standards, ISO 14000 standards for environmental management systems are being developed to formalize the LCA method components [3]. Figure 3 presents a classic Product Lifecycle process. Each stage of the loop includes cost, and environment impacts (consumption and pollutions). Product life cycle costing and LCA aims at evaluating performances on an overall cycle and some times on multi-cycles. Blanchard emphasized the cost impacts of the early design stages of a product [4][5]. Except for the use phase, the development step (before manufacturing) allows more than 90% of the future global product costs. In the case of environmental impact, there are no similar data available, but we assume that the ratio should be quite similar. For a whole lifecycle evaluation, cost or environmental indicator definition and estimation is equally as difficult. This section emphasizes the need for integrated information models and expert viewpoints to tackle the whole life cycle evaluation of a product or a service.

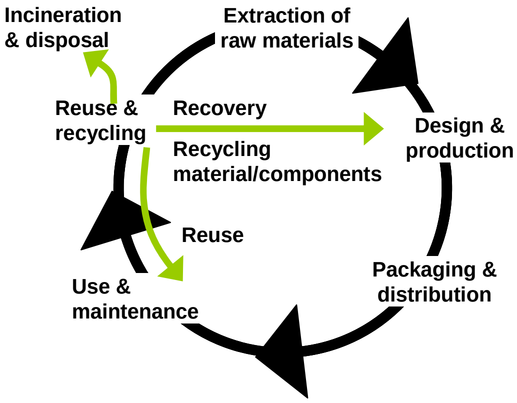

Figure 3. Product Lifecycle process

2.1 Full lifecycle model

Total lifecycle modelling is unachievable. Indeed, specific lifecycle phases have complete definition due to the possible detail of the basis activities (that consume costs or affect the environment). Moreover, costs become shared results for a network of stakeholders [6]. They shift from a productive industry (mainly direct costs linked with manufacturing costs) to a cognitive and world wide networked industry (with major allocations related to indirect costs linked with study and developments stages) [7]. As a result, the product lifecycle phases are already partially formalised. These phases can be more easily populated and monitored. Indeed, the process definitions (required by ISO 9000 standards) provide a good basis for extracting and aggregating manufacturing costs. However, in a world where innovation and R&D projects maintain the competitive, these indirect loads are not easy to assess with real data. At the end of the product lifecycle, there is no rule that guides designers in the whole costs impacts on the final estimate. Depending on the alternatives, some financial advantages can be introduced into the loop. For example re-use as second life sub-systems or material recycling can generate positive financial flow and reduce the global bill.

The same problems arise from environmental indicators. They have to take consumption of resources into account (mainly raw materials and energy), different types of pollution and emissions (solid, liquid, gaseous) and their impacts (human, eco-system, ground, water, atmosphere …). As for cost analysis, some life phases or resource consumption can be monitored easily, such as power supply factories, distribution in a known supply chain, etc. However, in a continuously moving network of enterprise, many measurements depend on the networks dependences. Consequently the evaluations may be inaccurate during the product development. The real choise of suppliers uses criteria far from the environmental scope. Moreover, the end of life may have a great impact. Depending on the existing recycling paths, or developed technology, this impact could be positive and enhance the global environmental dependence. Burning or landfill solutions will no longer have a future. Industry and designers have to consider this impact in their future designs and developments. Automotive regulations for 2015 will limit the percentage of CO_2 emission but also impose a high ratio of recycling for vehicles at the end of life.

The use phase of a product is hard to evaluate. In Business-to-Business relationship, this phase is quite well defined and could lead to good evaluations. Whereas Business-to-Consumer products could lead to unusual uses which lead to unexpected costs or environmental consequences. In the case of a LCA, the life phase may be the most noxious. Designers and industry have little impact on it. Here starts the limits of designers possibilities. Only efficient information and tutoring of the customers leads to reach real sustainable products.

Even if it seems impossible to completely define the whole lifecycle, similarities and complementarities arise from the two modelling points of view: cost and environment. In each case, the product evolutions have to be modelled and evaluated. Energy and material consumption are required data for both. Product transformations models are also sources of common rating. Thus, process and product models are used to perform cost analysis and LCA of products through different stages of manufacturing, use, and end-of-life options. The system can be analyzed using process flow diagrams. In these representations, the inventory of environmental impacts and resources used is comparable. It provides joint cost and environmental analysis [8][9].

2.2 Full lifecycle information

Most of the time, the expected information is only partially defined or not defined at all in the early phases when decisions are made [10]. As a result, it is hard to develop cost or environmental design strategies which could guide designers efficiently, due to these non-trustable values. Specific risks analysis evaluation should be done at the key stage of the product-process development. A contingency analysis would allow the variability of the results to be measured and highlight the main incident factors [11]. These methods are still under validation from an environmental point of view.

It seems possible to have detailed information on some stages like manufacturing, packaging and transport or from the recycling processes. Even in these cases, the real data are not so easy to capture [12]. Nowadays, the supply chain is world wide, and the reality of modelled processes and data collection are hard to guarantee [13]. This is the case for cost evaluation and the environmental aspect despite the standard framework imposed to the suppliers.

Consequently, calculations must be made using unknown data and have to be interpreted as relative values in most of cases. Thus ranking a new product or product process alternative might be hazardous.

2.3 Multi data aggregation

Another common issue remains regarding the needs for calculation with multiple kinds of data. In the case of LCA, the environmental impacts included are: global warming, acidification, energy use, non-renewable consumption, water eutrophication, gaz and toxic emissions to the environment, etc. This combination of multiple and non-homogeneous data highlights the issue of indicators design and equivalence definition. Some research proposals have started working on unified metrics unities. For instance, they propose decibels as a possibility. This solution has no unity dependence and indicates the contribution or losses of the value (the decibel is calculated as a ratio compared to a nominal value). The energy equivalent calculation is another possibility. This thermodynamic concept suites to measuring material and energy resource consumption for each impact [14][15][16].

In the same way as having a unique cost indicator, Perrin promoted the single value added unit methodology [17][18]. This proposal tries to find an independent cost unit that could facilitate the real representativeness and the final aggregation. In fact, Perrin realised that the analytical accounting system is not adapted to industrial reality. In the same philosophy of cost independence, target costing or activity based costing approaches were developed and adapted to use and integration in design methodologies [19][20][21].

Based on these studies, the concept of value promoted by Porter arises as a global and transitional concept applied to both costs and environmental analysis [22][23]. Indeed, traditionally value includes different factors such as cost, quality, delay, and enables value chain evaluation and optimization to be carried out [24][25]. This notion of value could easily be extended to environmental aspects.

3 LIFECYCLE ENGINEERING AND PRODUCT LIFECYCLE MANAGEMENT BASED ON VALUE EVALUATION

As mentioned in the previous section, whole lifecycle evaluation means formalization and information at all stages of the product development. Nevertheless, the product itself cannot be the only focus. The processes that support product development, manufacturing, using step and end of life dismantling also have to be taken into account. As a result, the information system that supports such approaches must take both product/process into perspective as well as different stakeholder viewpoints [26].

PLM systems rely on a data model composed of business objects that intervene in business processes and in product portfolios. Several modelling methods and languages have been developed to model these objects. Many languages enable the representation of these objects and related activities like SADT or IDEF3, Business Process Modelling Notation (BPMN) [28] or Functional Behaviour Structure (FBS) coupled with Product Process Resources and External effects (PPRE) [29]. The establishment of patterns, based on this language, describes an approach to represent the processes. CIMOSA [30], ARIS [31], GRAI [32], PERA [33] are modelling languages and modelling methodologies that must be adapted for PLM implementation.

3.1 The value nutshell for cost and environment combined analysis

To ensure an efficient twin-eco evaluation (economic and ecological), it is necessary to quantify the alternatives for product and processes. This quantification will be functional, economical and environmental. In order to take into account stakeholders viewpoints, each aspect has to be weighted. The final choice will be made according to the strategy or the enterprise objectives.

Value is a concept that enables different factors to be analyzed independently or in combination. Performance and value indicators, presented in Figure 4, come from a reflection on the benefits of product manufacture for each benefiting entity [25][26].

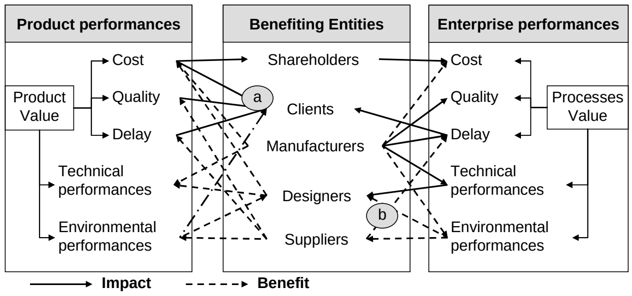

Figure 4. Performances that affect value and their interactions with benefiting entities [25]

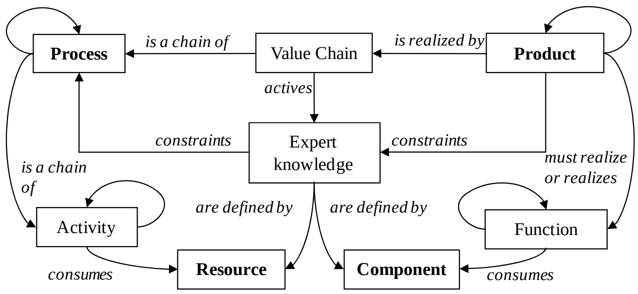

Figure 5. Structure of the concepts for industrial system modelling

Mauchand proposes a product-process data model focusing on the value chain modelling and evaluation (figure 5) [25]. This model needs to integrate lifecycle concepts in order to enrich the value concepts with environmental concerns. For example, the process can be extended to product stages, and will represent all the steps illustrated in figure 3. Labrousse links the Product Process Ressources model to the Functional Behaviour Structure view. This solution gives the opportunity to manage both value and value chain evaluation (while using the model in figure 5) and the dynamic aspect of the life cycle evaluation.
From a product (set of N functions), different technical solutions meet the needs. In addition, for each solution, the processes alternatives (composed of a set of activities) can lead to the product development and use. For each path, a value chain can be defined as illustrated in Figure 6.
Using this method, Mauchand proposes a Value Chain Simulator (VCS) that can compare solutions. Depending on the weights applied related to the benefiting entities interest, the solution will balance high technical performances oriented possibilities, low costs (or adapted market) solutions and environmentally friendly proposals. The structure and basic elements of the VCS are illustrated in Figure 7.

Despite all the qualities of this proposal, there is still something missing in terms of lifecycle simulation with such tools. Indeed, the model and data system required for the simulation are hardly complete. Moreover, this tool has mainly been dedicated to the manufacturing phase [25] and must be adapted to the other product lifecycle stages.

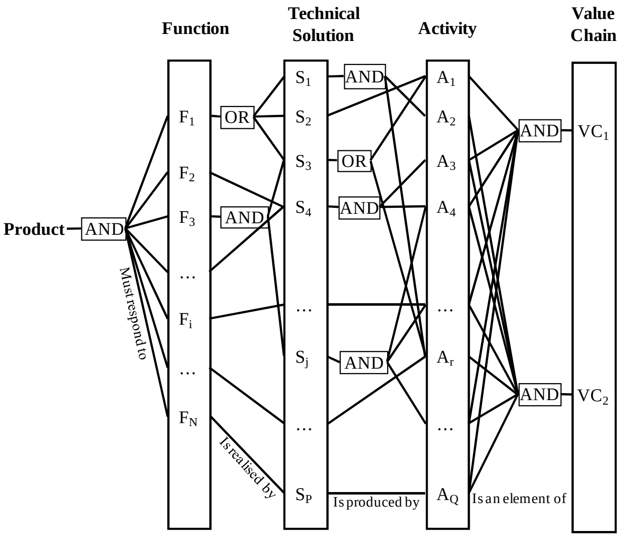

Figure 6. Choice process of value chains alternatives

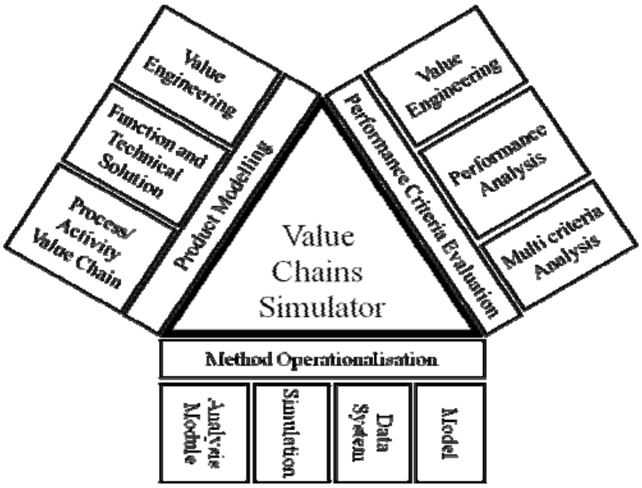

Figure 7. Value Chains Simulator Architecture [25]

3.2 PLM system definition

In order to ensure a full product lifecycle evaluation, the life model and life used phases have to be represented and completed with relevant data.

LeDuigou proposed a PLM structure adapted to SME's. Supported by the French Technical Institute of Mechanical Industries (CETIM), this work wants to provide a solution for the SME's. With this PLM information system, they can get into an extended enterprise structure with measured investments and time [34]. Based on product – activity – resources – organization meta data structure (see Figures 8 and 9), this proposal has to be aligned with the previous value based one, in order to allow its use for assessment of the product lifecycle model.

This PLM proposal is based on SME's needs and requirements analysis [35]. Consequently, it is not completely adapted to the cost and environmental evaluation. Indeed, the different indicators measures can be implemented at all the levels: product, activity, resources and organization. It appears that if these data are available, the activity and the resource views could quickly give pertinent ratings. In the case of the product, the different lifecycle steps are represented by the different activities linked to the product (design, manufacture, use, disassembly…). In the case of the uses phase, alternatives uses (id es non-nominal) are represented by alternative activities of the normal use. This allows evaluating the product and the customers' impact (depending on its behaviours). This example gives an idea of what a PLM system with evaluations facilities could be.

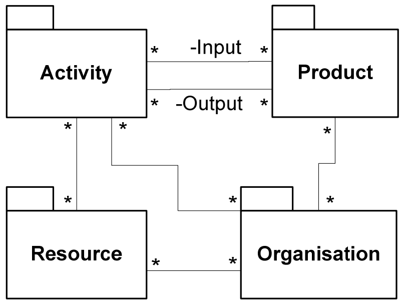

Figure 8. Product Activity Resource Organization meta-model

4 KNOWLEDGE MANAGEMENT FOR VIRTUAL ENGINEERING BASED EVALUATIONS DISCUSSIONS

In order to ensure high quality and efficient evaluations, the model should not only be adapted to the whole lifecycle, but the calculated rank should also be proposed with contextual information and the data that reflect reality. Calculation and aggregation rules, data sources reliability and model representations must be available for the contextualisation of results. Consequently, knowledge from different experts must be integrated in knowledge based systems. This system must be interoperable with all the specific tools from the modelling phase and the data capture to the evaluation and results comparison or optimization. Virtual engineering environments allow the integration of all the lifecycle models. Engineers have new media to interact with the different numerical representation and simulation models. They use them for definition and industrialization of complex systems that must integrate more and more perspectives in a short time. The challenge is in the improvement of product development environments and the design of virtual engineering platforms software that take all the phases of product and system lifecycle into account [37].

Consequently, knowledge tracking, identification and formalization, from different expertise, at different levels of detail must be carried out and integrated in knowledge-based engineering platforms. Specific methods ensure the coherence and consistency of these knowledge based system developments [38]. In order to ensure the multiple expertise coherence and interoperability (from the knowledge and software point of view) various integration models exist, and ontology based approaches seem very promising for the future 2.0 technologies [39][40]. For instance specific ontology definition of concepts like cost has already been proposed [41] and can be combined with environmental or sustainability ontology [42].

Exchanged documents and previous projects are the information repository areas that can be exploited to enrich the expected knowledge (on costs and on environmental evaluation) [43]. From these documents, key knowledge can be identified. Xu proposes a knowledge value rating system that allows the optimization of the best evaluating models, representative methodologies or efficient software that should be used to quickly and sharply answer the product or systems cross evaluations [44][45]. This proposal gives the potential of pertinent selection for evaluation techniques, depending on the level of product development, information maturity, perspectives and target constraints. Such an operational system is not yet in use. Indeed, the basic compounds of knowledge evaluation have been proposed and offer promising possibilities to browse and select the most efficient and pertinent elements to be integrated into the global knowledge database. The wish to integrate the knowledge of several experts to all phases of the product life cycle leads to a huge system that is unmanageable and unusable. Information reduction coupled with intelligent information technologies (id. es. 2.0) can reduce these risks.

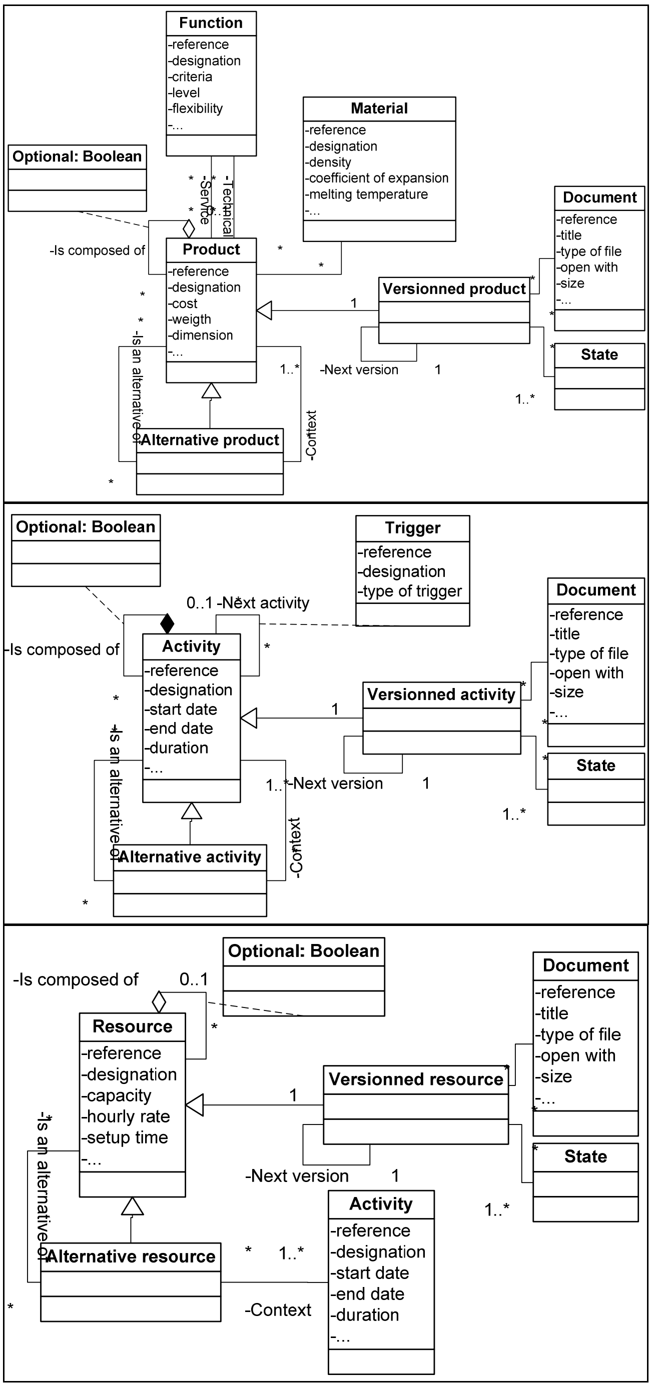

Figure 9. Product – Activity and Resource models [36]

5 CONCLUSION

This paper highlights the complementarities of cost and environmental estimate. The same needs and limits for whole lifecycle evaluation appear for cost or environmental application. The modelling level lacks some lifecycle phase's representation due to absent data or unknown solutions for these phases. The data capture level for simulation lacks accuracy or sensibility analysis for evaluating the quality of the results in terms of confidence or main factor impact. The performance indicators, cost or environmental impact, can be analyzed separately or shared in a common nutshell such as the value concept. Therefore PLM possibilities, dedicated to data management and information management of product regarding its lifecycle, can be adapted to support the different eco's calculations (from an economic and/or ecological point of view). Moreover, to ensure a good level of results contextualisation and best practices integration, expert knowledge integration must be included in a knowledge database. These knowledge databases are structured to support the definition and the development of agile virtual engineering platforms. Indeed, the modelling tools might be different from one phase to another. The kind and quality of information will be at different levels. In order to maintain coherence and ensure agility with future software integration in the engineering method, ontology based systems can offer solutions for service oriented architecture for platform development.

This type of global approach cannot be addressed in a single project or test case, but results from development strategies of the different identified bricks and their integration in a coherent global proposal.

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